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Session: MARINE ARCHAEOLOGY: A PROBLEMATIC APPROACH TO RESOLUTION OF UNIDENTIFIED MAGNETIC ANOMALIES

Chair: Mr. Richard J. Anuskiewicz

Date: November 6, 1986

Presentation Title	Speaker/Affiliation
Marine Archaeology: A Problematic Approach to Resolution of Unidentified Magnetic Anomalies: Session Overview	Mr. Richard J. Anuskiewicz Minerals Management Service Gulf of Mexico OCS Region
Summary of Thoughts of Theoretical and Practical Considerations for the Improvement in the Interpretations of Magnetic Survey Data	Dr. John W. Weymouth University of Nebraska
Resolution of Unidentified Anomalies and Related Matters	Mr. J. Barto Arnold III Texas Antiquities Committee
An Analytical Consideration of Three Interpretative Anomaly Parameters - Amplitude, Signature, and Duration	Dr. Ervan G. Garrison Texas A&M University
Response to a Problematic Approach to Resolution of Unidentified Magnetic Anomalies	Mr. Allen R. Saltus, Jr. Southeastern Louisiana University
Geophysical Search Techniques for Distinguishing Shipwrecks from Trash	Dr. Bruce W. Bevan Geosight

Marine Archaeology: A Problematic Approach to Resolution of Unidentified Magnetic Anomalies: Session Overview

Mr. Richard J. Anuskiewicz
Minerals Management Service

Every year Minerals Management Service (MMS) archaeologists review hundreds of geophysical - archaeological reports containing geological interpretations and an archaeological assessment of lease blocks located in Federal OCS waters of the Gulf of Mexico. As a part of the archaeological review for these lease blocks, a historic analysis is conducted to assess the potential impact of future oil and gas development on possible historic shipwrecks located within these lease blocks. In the process of reviewing the geophysical - archaeological reports yearly, MMS archaeologists look at thousands of unidentified magnetic anomalies recorded during marine magnetometer surveys presented in these reports. These thousands of unidentified anomalies are scrutinized and an attempt is made to discriminate between a potential historic shipwreck and modern marine debris.

In order to attempt to develop a better analytical capability to discriminate between potential historic shipwrecks and modern marine debris, a panel of experts--experienced in theory, method, instrumentation deployment, and data interpretation of magnetometer remote sensing -- was formulated.

The panel members were given two geophysical - archaeological lease block survey examples for review, and copies of MMS's Notice to Lessees (NTL 75-3, Revision No. 1), and Letters to Lessees (July 17, 1984 and March 5, 1986) which detail MMS's magnetometer survey requirements for OCS archaeological surveys.

The marine archaeology sessions focused on specific analytical factors that provide the existing interpretive framework in MMS's analysis of magnetometer data for archaeological reports. MMS archaeologists have been reviewing magnetometer data and using these analytical factors in an attempt to discriminate between potential historic shipwrecks and modern debris. Hopefully, these sessions will expand the present state of knowledge in marine magnetic interpretive skills to better increase discriminative capabilities. Listed below are the analytical factors used in MMS's present archaeological interpretive framework: (a) anomaly amplitude in gammas; (b) signature width and/or duration in time; (c) signature asymmetrical characterization; (d) sensor height above the seafloor; (e) spatial occurrence of anomaly due to existing oil and gas production facilities, designated anchorage areas, shipping fairways, and military warning areas; (f) the existence of predetermined high- and low-probability zones for the occurrence of historic shipwrecks; and (g) whether or not the anomalies correspond to existing geologic features.

Given MMS's 150-meter magnetometer survey line spacing interval, the panel discussants began the session.

Dr. John W. Weymouth, University of Nebraska, had several thought provoking suggestions for both magnetic data acquisition and data interpretation of survey data. Within the existing 150-meter survey methodology, Dr. Weymouth suggested: a) providing copies of all chart recordings of magnetic anomalies; b) all information available to include, factor translating time on charts to horizontal distance, time at the start of each run, magnetic amplitude, and horizontal distance between readings to estimate size and nature of the magnetic source; c) use of the "full width, half maximum" (FWHM) number which is obtained from a simple profile by measuring the width of the profile at an amplitude halfway between the maximum value and background; d) the concept of "anatomy of anomalies" should be studied within the framework of an examination of anomalies produced by actual shipwrecks and non-shipwrecks that have been tested by excavation and by model calculations using realistic sources and simulating the survey methods being used; and e) within the existing survey methodological framework add another magnetometer in a side-by-side array at a separation distance roughly comparable to the anticipated sensor-to-source distance.

J. Barto Arnold III, the state marine archaeologist for Texas, pointed out a basic flaw in plan in MMS's existing 150-meter line spacing methodology, and drew on his past experience, suggesting that the distance between lines is too great to develop patterns of readings on neighboring survey tracks which are essential in recognizing a shipwreck. He further stated that even assuming adequate coverage by close survey tracks, it may be there are too many independent variables to ever be completely sure about anomaly causes without physical visual inspection. Current MMS survey line spacing requirements present an insurmountable barrier to better interpretation of the magnetic records. There are, nonetheless, some actions that should be taken to immediately vastly improve the (archaeological) reports. A gathering and analysis of anomaly signatures which have subsequently been ground truthed would be a big step towards seeing what can be done and how far we can go with our interpretations and the confidence level appropriate in those interpretations. In addition, the section of magnetometer strip chart showing every anomaly recorded should be submitted with the archaeological report for review and interpretation.

Dr. Ervan G. Garrison, Texas A&M University, talked about an experimental magnetometer survey he conducted over a 19th century historic shipwreck. This well-known and diver-surveyed Civil War shipwreck, the "Will O' Wisp," lies approximately 300 meters off Galveston Island, Texas. A total of six survey transects, one directly over the wreck and thence out to 150 meters at 25-meter line spacing intervals, was run. The six separate transects were then analyzed for the relative discriminatory power of the three parameters of amplitude (intensity), signature (shape), and duration (period). The set of magnetic survey data, taken with high precision, was evaluated using these three parameters. Typically used in MMS's standards for evaluatory purposes, these parameters were analyzed for their relative discriminatory power in characterizing magnetic anomalies. Based on the preliminary results of the study, only one--<u>duration</u>--was instrumentally significant over survey transects a hundred meters distant from the anomaly source: in this case, a 19th century historic shipwreck.

Professor Allen R. Saltus said that MMS archaeologists should be commended for their attempt to utilize all available data to the fullest, but their interpretive framework should not be used in formulating a final determination as to the cause of any magnetic occurrence, including debris from shipwrecks. In doing so they could be writing off cultural resources without knowing anything of their nature or significance. However, given sufficient data, the interpretive factors could be useful for planning purposes. The only method of determining cause and significance of magnetic data is through ground truthing (i.e., diver verification, underwater television, and sometimes die scan sonar). This statement is based on a discussion of survey methodology used to gather this magnetic data and the seven interpretive factors used by the MMS archaeologists.

He continued by saying that the magnetic data gathered to fulfill the MMS guidelines is generated at 150-meter (492.39 feet) line spacings. Using this methodology, no known pre-World War II watercraft is guaranteed to be detected. Actually, most vessels have less than a one in four (25%) chance of being located. Smaller watercraft have less than a one in five (20%) chance of being located. At 150-meter line spacing, the survey can only be considered an exploratory or sample survey from which further investigations can be determined and/or planned, and budgetary needs established for the next phase of investigation. The MMS archaeologists are attempting to short cut this process using analytical methods which do not seem to have any acceptable degree of significance or reliability regarding their criteria for differentiating debris from shipwrecks.

In summary, Professor Saltus suggested that he hoped that the criteria established by the MMS archaeologists will not be used. To do so could create a situation in which a Federal agency may write off significant cultural resources by using both an unacceptable database and manipulating this data using criteria which do not have an acceptable degree of reliability or significance. Using this approach would lend credence to the term used by critics of this program, "Archaeofolly."

Dr. Bruce W. Bevan of Geosight stated that magnetic surveying has been a successful procedure for locating shipwrecks, but many false indications from modern discarded iron are also found. It is possible that changes from current survey techniques could increase the reliability of distinguishing shipwrecks from trash on the seafloor. Triaxial vector magnetic measurements have greatly aided the search for magnetic materials from boreholes. These same procedures could be applied to estimating the depth of iron in the sediment and therefore could suggest its age.

Handheld metal detectors have been applied to search for artifacts at shipwrecks, but other instruments could be more suitable for large area investigation of insulators and conductors. Electrical resistivity measurements can be made on the seafloor by dragging an electrical cable with several connection points exposed to the seawater. Magnetotelluric surveys typically measure to a great depth, but might be suitable for this survey.

Old iron could be significantly different from modern iron in its magnetic properties. An electromagnetic induction system which measures the electrical conductivity of the seafloor could also determine its AC magnetic susceptibility. Measurements at one or more frequencies might allow different ferrous materials to be distinguished. With the vector magnetometer mentioned above, it could be possible to separate the remnant and inducted magnetization of iron objects by determining the net direction of polarization. The ratio of remnant to inducted magnetization, the Koenigsberger ratio, might distinguish old iron from modern steel.

Richard J. Anuskiewicz obtained a B.A. in 1972 and an M.A. in 1974 in anthropology/archaeology from California State University at Hayward. He was employed with the U.S. Army Corps of Engineers from 1974 to 1984 as a terrestrial and marine archaeologist and worked in San Francisco, New England, and Savannah Corps of Engineers District Offices before accepting a position with the Minerals Management Service Gulf of Mexico OCS Regional Office in 1984. Mr. Anuskiewicz took a year's leave of absence for graduate school at the University of Tennessee in Knoxville, and in February 1982 he was advanced to doctoral candidacy. His current research interests are marine remote sensing and underwater archaeological site reconstruction in a blackwater environment.

Summary of Thoughts of Theoretical and Practical Considerations for the Improvement in the Interpretations of Magnetic Survey Data

Dr. John W. Weymouth
University of Nebraska

The meeting was a panel and audience discussion of theoretical and practical considerations for the guidance and improvement in the acquisition and interpretation of magnetic survey data of lease blocks for the purpose of mitigating the impact on archaeological resources.

1. Within Existing Methodology

Although the present form of obtaining magnetometer data (running traverses 150 m apart with one magnetometer and side scan sonar) can only provide anywhere from 10% to 30% coverage of possible shipwreck indications, it is realized that there are severe economic restrictions to providing greater coverage. Within this framework, several things can be done to improve the interpretation potential of the data that are obtained.

a. Copies of all chart recordings of magnetic anomalies should be provided. In order to extract the fullest possible information from the data, it is not sufficient to have just the maximum and total length of the anomaly. It is necessary to see the shape and structure of the anomaly profile. Having the original profile will aid in separating simple sources from complex sources.
b. Full information should be provided, and this includes sensor distance above bottom, factor translating time on charts to horizontal distance, and time at the start of each run. The magnetic amplitude and horizontal distance between readings can be used to estimate size and nature of source. The time of recording the anomaly can be used in conjunction with the geomagnetic information provided by NOAA (Preliminary Report and Forecast of Solar-Geophysical Data) to account for possible deviations from the normal magnetic diurnal curve.
c. If a "width" number is going to be used, it should be the "full width, half maximum" or FWHM. This number is obtained from a simple profile by measuring the width of the profile at an amplitude halfway between the maximum value and background. The width should be expressed in horizontal distance along the traverse. This measure is less ambiguous than duration of anomaly and is widely used (M. Aitken, Physics and Archaeology, 2nd Edition, 1974, p. 217; J. Weymouth, Chapter 6, Advances in Archaeological Method and Theory, M. Schiffer, Ed, Vol. 9, 1986, p. 344).
d. The "anatomy of anomalies" should

be studied in relation to these data. This should include 1) an examination of anomalies produced by shipwrecks and non-shipwrecks that have been subsequently tested by excavation, 2) model calculations using realistic sources and simulating the survey methods being used.

e. Within the framework it should be possible to add another magnetometer without a large increase in cost. The two sensors should be run side-by-side at a separation distance roughly comparable to the anticipated sensor to source distance. This should provide valuable information as to the lateral direction of sources as well as some clues as to the size of the sources.

2. Beyond the Existing Methodology

a. Obviously the single most important step beyond the present method would be to reduce the distance between traverses. In fact, the ideal would be to have that spacing equal to the sensor-to-source distance. This is unrealistic, but any reduction in distance would be an improvement.

b. Bruce Bevan's suggestion of using vector measurements of the anomalous field should be examined, first with mathematical model calculations, then with testing, to see what additional information this would provide.

c. I do not think that a base station is needed in most situations. Such a station would be operated continuously on the shore in the general area of the survey. This would provide data for correcting the temporal variations in the magnetic field during the time of the survey. This would eliminate spurious or false anomalies that could arise from brief, sharp spikes in the magnetic field occurring during a survey. This would not happen very frequently, and considering the nature of the data that is obtained, it probably is not urgent. If the expense of establishing a base station is not great, it could be tried, and the results obtained on geomagnetic active days could be examined for any improvement.

Dr. Weymouth obtained his B.S., M.S. and Ph.D. degrees from the University of California, Berkeley (Ph.D. in 1952). He is currently a Professor in the Department of Physics and Astronomy, University of Nebraska. He also holds an appointment in the Anthropology Department at UN. His original field of research was solid state physics, but in 1971 he turned to archaeometry. After some work with x-ray diffraction and x-ray fluorescence, he concentrated particular emphasis on magnetics. He has been involved in surveys in over ten states in the USA, plus surveys in Japan, France, and Hungary.

Resolution of Unidentified Anomalies and Related Matters

Mr. J. Barto Arnold III
Texas Antiquities Committee

Several factors cause a problem relating to the identification of the causes of magnetic anomalies when we are limited to only the magnetometer records in making the interpretation. For the OCS surveys the first and foremost problem is the lane spacing. The 150 m distance required is too great to develop the patterns of readings on neighboring tracks which are essential in recognizing a shipwreck. Many marine archaeologists have pointed this out through the years in various articles and papers including previous MMS-ITM meetings (Arnold 1982 Appendix I). Given this basic flaw in the survey design, the only conclusion one can draw is that <u>any</u> anomaly <u>could</u> be caused by an historic shipwreck. Indeed, cases exist demonstrating that anomalies from substantial shipwrecks might be missed altogether at 150 m track spacing (Arnold 1982 -Appendix I, Arnold 1982 - Appendix II). Nevertheless, there are things to look for in the data that would indicate a more promising anomaly. A large multipeaked anomaly would be indicative of a possible wreck (Arnold 1982 - Appendix III). The trouble is that small single peak anomalies cannot be discounted due to the overly wide lane spacing. And, of course, a multipeaked anomaly could just as possibly be caused by a complex assemblage of modern debris.

Even assuming adequate coverage by close survey tracks it may be that there are too many independent variables to ever be completely sure about anomaly causes without physical visual inspection. The orientation of an object in the vertical and horizontal planes relative to the earth's field causes variation in the anomaly and, therefore, the magnetometer strip chart signature. So does the direction of the sensor as it crosses the object or the anomaly. There are also indications that anomalies produced by historic wrecks may not be detectable at as great a distance as one would predict from the inverse cube rule (Arnold, in press- Investigation of a Civil War Anti-torpedo Raft - Appendix II).

It must be said, however, that an experienced marine archaeologist <u>can</u> and does develop a sense of <u>which</u> anomalies look more promising than others.

To improve this situation there is at least one step that could be taken immediately. The section of magnetometer strip chart showing every anomaly reported in an OCS-CRM report should be illustrated. The same is true for side scan targets and subbottom profiler features. The reports would then become useful. The data analysis could be easily checked. In the past, original remote sensing data has not been archived like other archaeological data must be. Now many survey and oil companies have disappeared due to the decline of the domestic oil and gas industry. What has become of the data gathered by those companies? I fear that much of the data has been disposed of and, therefore, can never be reanalyzed or rechecked.

An urgent effort to salvage and retrieve the data gathered by now-defunct firms should be a top priority of the MMS.

In addition to this new report requirement, there should be an additional new requirement to archive a legible copy of all data with the MMS.

Another idea productive of a better interpretive situation vis-a-vis magnetometer strip chart data would be to gather the anomaly records of sites that have subsequently been ground-truthed by diver examination and/or test excavation. An example of a paper presenting such data is presented in full in Appendix III (Arnold 1982). Many underwater archaeologists have such data. It should be systematically gathered by the MMS or a contractor and then analyzed.

A minor matter that could easily be improved involves the references required for use in preparation of OCS-CRM reports (cited in Sieverding letter of 17 July 1984 - (LE-51 LE-2)). A number of additional later publications than the Calusen and Arnold article cited are included in Appendix II. These should be added along with others by other authors.

I noticed in the advanced material for this meeting that a copy of one of the Archaeological Report Reviews prepared by the MMS staff archaeologists was sent to the appropriate SHPO. Is this done regularly, and is a copy of the report itself sent? They should be.

In conclusion, current OCS survey lane spacing requirements present an insurmountable barrier to better interpretation of the magnetic records. There may be too many independent variables to ever get very far with or be very confident of interpretations based on the magnetometer alone. There are, nonetheless, some actions that should be taken to immediately vastly improve the reports. A gathering and analysis of anomaly signatures which have subsequently been ground-truthed would be a big step toward seeing what can be done and how far we can go with our interpretations and the confidence level appropriate in those interpretations.

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J. Barto Arnold III is a native of San Antonio, Texas. He received his B.A. and M.A. in anthropology/archaeology from the University of Texas at Austin. He is the State Marine Archaeologist for Texas and has served in that position since 1975.

An Analytical Consideration of Three Interpretative Anomaly Parameters - Amplitude, Signature, and Duration

Dr. Ervan G. Garrison
Texas A&M University

A set of magnetic survey data taken with high precision was evaluated using these three parameters. Typically used in Minerals Management Service (MMS) standards for evaluatory purposes, these parameters were analyzed for their relative discriminatory power in characterizing magnetic anomalies. Based on the results of the study, only one--duration--was instrumentally significant over survey transects a hundred meters distant from the anomaly source: in this case, a 19th century historic shipwreck.

EXPERIMENTAL CONDITIONS

A set of magnetic survey data representing six separate transects over a 19th century shipwreck was analyzed for the relative discriminatory power of the three parameters--amplitude (intensity), signature (shape) and duration (period). The data were obtained under optimized conditions of environment and survey. Every attempt was made to maximize the precision of the data in terms of repeatability for survey and instrumental conditions over the study. The anomaly was a well-known and diver-surveyed Civil War shipwreck, the Will O' The Wisp, lying 300 meters off Galveston Island, Texas, in three meters depth of water.

A total of six survey transects, one directly over the wreck and thence out to 150 meters, were run. The data appear in Tables 10.1, 10.2, 10.3, 10.4, 10.5 and 10.6 and represent a sequence of survey lines of 0, 50, 75, 100, 125 and 150 meters distance, respectively, from the wreck. These data were evaluated graphically and numerically for the discriminatory value as regards the characterization of a magnetic anomaly by amplitude, signature or duration.

ANALYSIS AND RESULTS

1. Amplitude -- The maximum intensity of the anomaly was scaled to the earth's field value for that time and plotted versus distance (in meters) from the wreck. Table 10.7 shows these values.

   The data show an expected fall in the intensity, roughly on the order of magnitude, expected for relation of amplitude to the inverse cube of the distance. Intensity falls markedly after 50 meters.
2. Signature -- These data were graphically analyzed at the same scale, +3000 to -3000 nanoteslas (lines 1-6), and a scale of +50 to -50 nanoteslas for lines 2-5. The key element examined was signature shape in the relatively scaled lines. Inclusion of lines 1-6 data showed the large dipolar signature of the line 1 anomaly at the expense of the clear visualization of the anomaly on lines 2-6. The removal of the line 1 trace allowed a better appreciation of these signatures at an equivalent scale.

   Individually, scales were adjusted to maximize shape discrimination, and each line's signature was evaluated.

   The results are summarized in Table 10.8. The results show delineation of a repeatable signature up to 50 meters. The signature at 75 meters is clearly discernible, but showed little similarity to that seen on lines 1 and 2.
3. Duration -- Again plotted graphically, duration of the anomaly was scaled from first detection of a consistent instrumental deflection to the loss of same. The total time of the anomaly was plotted as the duration and is shown in Table 10.9.

   Examined statistically, there was no significant difference between the values seen for duration over lines 1-4. Taken with the values for lines 5 and 6, the fall-off in the value of duration is significant at the .95 level.

CONCLUSIONS

Of the three variables examined,

1. Amplitude was found to be not diagnostic after 75 meters.
2. Signature repeatability was not observed after 75 meters.
3. Duration was observed at the same level of repeatability at 100 meters.

Duration was found to be the most reliable variable in detecting the anomaly over distance.

Dr. Ervan G. Garrison is an archaeologist and a lecturer and associate research scientist of civil engineering at Texas A&M University. His research interests include the application of geophysical instrumentation to the study of archaeological problems onshore and offshore.

Response to a Problematic Approach to Resolution of Unidentified Magnetic Anomalies

Mr. Allen R. Saltus, Jr.
Southeastern Louisiana University

Archaeologists for the Minerals Management Service (MMS), Gulf of Mexico Region have been reviewing magnetometer data and have proposed to use analytical factors in an attempt to discriminate between historic shipwrecks and modern debris. The analytical factors used for this interpretive framework include

1. Anomaly amplitude, in gammas.
2. Signature width and/or duration in time.
3. Signature asymmetrical characteristics (i.e. dipole and monopole).
4. Sensor height above seafloor.
5. Associated anomaly occurrence (anchorage, shipping fairway, military warning areas, gas- and oil-producing facilities and pipelines).
6. Anomalies corresponding with geological features.

The MMS archaeologists should be commended for their attempt to utilize all available data to the fullest, but the above criteria should not be used in formulating a final determination as to the cause of any magnetic occurrence. In doing so, they could be writing off cultural resources without knowing anything of their nature or significance. However, given sufficient data, the above factors could be useful for planning purposes. The only method of determining cause and significance of magnetic data is through ground-truthing, i.e., diver verification, underwater television and, sometimes, side scan sonar. This statement is based on the following discussion of survey methodology used to gather this magnetic data and the seven factors used by the MMS archaeologists.

The magnetic data gathered to fulfill the MMS guidelines is generated at 150 meter (492.39 feet) lane spacings. Using this methodology, no known pre-World War II watercraft is guaranteed to be detected. Actually most vessels have less than a one in four (25%) chance of being located. Smaller watercraft have less than a one in five (20%) chance of being located. Table 10.10 is a list of selected magnetic anomalies for which we have fully executed magnetic contour maps of magnetic source areas and amplitudes. The table includes single magnetic sources, multiple magnetic sources, and wrecks. The table lists the height of sensor from the object(s) being detected, size of object(s) being detected, magnetic area being magnetically affected at that sensor height, and maximum magnetic inflection produced by the object(s) being detected. At 150 meter lane spacing, the survey can only be considered an exploratory or sample survey from which further investigations can be determined and/or planned, and budgetary needs established for the next phase of investigation (Murphy 1980; Murphy and Saltus 1981). The MMS archaeologists are attempting to short-cut this process using analytical methods which do not seem to have any acceptable degree of significance or reliability regarding their criteria for differentiating debris from shipwrecks.

The seven MMS criteria for determining wreckage from modern debris using the magnetic data generated at these line spacings all have varying degrees of problems. These problems will become apparent by discussing each criterion's limitations, using the table of selected magnetic anomalies and other pertinent magnetic examples.

The anomaly's amplitude, in gammas, is a function of both the distance of the sensor from the object(s) being detected and the chance occurrence of the transect over the magnetic field. The amplitude is not only determined by the distance of the sensor head to the magnetic source, the mass of the object, and the magnetic quality of the magnetic source, but also by the magnetic sources orientation in the earth's magnetic field. This last factor has particular importance for linear objects. If the linear object is lying in an east/west direction opposed to a north/south direction, then the area below the earth's ambient magnetic field (magnetic low) could increase and constrict the area above the earth's magnetic field (magnetic high), thus making the detection of the "full" magnetic amplitude even harder to detect even if closer lane spacing were used. The chance of the transect passing in the area to record the maximum magnetic high and low area is far greater than the chance of detecting the material itself. In reviewing Table 10.10, it is apparent that single objects can produce a far greater and sometimes smaller magnetic amplitude than some shipwrecks. Without knowing over what portion of the magnetic field the transect was run and how far the sensor is from the source, the size of the mass cannot be determined, much less whether the mass is a shipwreck or debris.

The signature width and/or duration in time may also be a function of chance depending upon where the survey transect crossed the magnetic field along with the unknown factors of: (a) orientation of the object(s) within the earth's magnetic field; (b) magnetic quality or qualities of the material being detected; and (c) the accumulative magnetic effect of the association and orientation of cultural material to the survey transect. An examination of the selected magnetic anomalies in Table 10.10 indicates an apparent spatial overlap in the size of the magnetic field areas produced by single and multiple objects, by multiple objects and shipwrecks, and by single objects and shipwrecks.

Signature asymmetrical characteristics (i.e., monopole or dipole) are, again, a function of chance determined by location of the transect over the magnetic field, orientation of the source of the magnetics, and nature of the source single object, multiple objects, orientation and association of these objects. In the case of the Star of the West (Saltus 1976) and the schooner James Stockton (Saltus 1985) there are areas below the ambient magnetic field on either side of an area of above the ambient readings. If on a single pass, one of these magnetic low areas were encountered there would be no way of anticipating, predicting, or knowing the nature of the total magnetic area, and it would have to be classified as a monopole when it is neither a monopole or a dipole but a complex magnetic anomaly area. Also there would be no way of determining on which side of the magnetic low (below ambient magnetic field) the magnetic high (above the magnetic ambient field) is located as in the cases of the two above mentioned wrecks.

Sensor height above the seafloor as a criteria is also a function of sensor distance from the magnetic source. If there is collaborating data such as a feature on the side scan sonar record, then analytical interpretation may be possible, but using the magnetic data alone, there is no way to know the sensor-to-magnetic-source distance, therefore, making any type of analysis futile for the above-mentioned rationale regarding amplitude.

Associated unidentified magnetic anomaly occurrences which may be located in anchorage areas, shipping fairways, military warning areas, and gas and oil field and pipeline production areas, represent a broad interpretative category. Gas and oil field pipeline production areas provide an existing magnetic anomaly data base of large and/or liner magnetic fields represented by well heads, platforms and pipelines and oil field platforms which could very easily mask historic shipwrecks. Elimination of anomalies related to shipping fairways could also eliminate possible shipwrecks lying in one of the high wreck probability areas.

Anomalies corresponding with geological features can also mask the presence of cultural material when viewed on a single pass. When the magnetics of the steamer Spray, 1852 construction date, is examined it is apparent that its magnetic field is incorporated with the magnetic field caused by pyrite nodule refuse. Only through a magnetic contour map is the vessel apparent (Saltus 1982). Hematite nodules found in remnant stream channels could conceivably produce low magnetics (J. Harding, personal communication). These magnetics could be within the magnetic amplitude and spatial area range of smaller shipwrecks. Drainage channels in some forms of clay with magnetic qualities have been observed producing 15 to 20 gamma anomalies (D. Bryant 1986). This too could be mistaken for a shipwreck using the MMS lane spacing.

There is no apparent degree of significance to any of the MMS criteria to differentiate debris from shipwrecks. Any such determination is subject to probability and chance, inherent in both the present methodology and the nature of magnetics as it applies to cultural material and, more specifically, multiple cultural material which occur in shipwrecks. If all the variables for interpretation were known, i.e., magnetic moments of the material(s) causing the anomaly, orientation of this material, masses of this material, distance of this material from one another, and the magnetic sensor head, etc., then we could better address the problem as to whether the nature of the magnetics was caused by debris or shipwreck. In almost all cases the anomalies, would have to be ground-truthed even if this agency were to use the 30-meter lane spacing developed by another federal agency, the National Park Service, as adequate for their needs to protect and manage cultural resources (Murphy 1982). Examples of magnetic conflicts between debris and shipwreck occur in fully mapped and contoured magnetic areas. An archaeological river landing site, 16EBR68, produced significant magnetic anomaly areas all of which upon diver investigation produced modern trash and debris while another river landing site, 16LV71, produced one anomaly which was considered relatively less significant than those produced at 16EBR68. Upon diver investigation, this less significant anomaly revealed three watercraft. A keeled vessel, scow barge, and section of a raft, were found, all more or less lying in a pile (Saltus 1986). A small coastal vessel found in the Wando River has less magnetic spatial area and magnetic amplitude than an anchor found in the same survey. Both of these historic materials were magnetically dwarfed by a World War II naval refuse, debris, located and diver identified (Watts 1979).

For the above reasons, it is hoped that the criteria established by the MMS archaeologists will not be used. To do so could create a situation in which a federal agency may write off significant cultural resources by using both an unacceptable database and manipulating this data using criteria which do not have an acceptable degree of reliability or significance. Using this approach would lend credence to the term used by critics of this program, "Archaeofolly."

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Geophysical Search Techniques for Distinguishing Shipwrecks from Trash

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There are several possible ways of distinguishing old shipwrecks from recent trash on the sea floor. Several ideas are presented here; these ideas are not necessarily original and may not be practical.

It is possible that the AC magnetic properties of old iron are different from modern steel. Steady magnetic fields would almost surely not aid this distinction.

The depth of iron below the sediments could approximate its age. Vector magnetic measurements along a single tow line might allow a determination of the distance of iron below the sensor.

If individual iron artifacts or clusters could be detected, identification of a shipwreck would be more certain. The spatial resolution of the magnetic survey would probably have to allow separation of objects spaced by 1-2 m.

High electrical resistivity could be associated with earlier wrecks having wood and ballast stone. This could be measured with a drag cable resistivity system, electromagnetic induction, or magnetotellurics. A single-source, multiple-sensor electromagnetic system could give high resolution measurements of conductivity and magnetic susceptibility.

Magnetic surveying has been a successful procedure for locating shipwrecks (Arnold and Clausen 1975; Hall 1972), but many false indications from modern discarded iron are also found. It is possible that changes from current survey techniques could increase the reliability of distinguishing shipwrecks from trash on the sea floor.

The high spatial frequency caused by the many iron artifacts at a wreck could aid its identification; the depth of burial within the sediments could be another guide. A wreck could also contain nonmagnetic, but conductive, metals and could have electrically resistive material such as ballast stone. It is also possible that old iron can be distinguished from recent steel trash by differences in magnetic properties resulting from differences in chemical composition and metallurgical structure.

Current magnetic search procedures have a sensor height of 3-6 m above the sea floor and a measurement interval of about 1 m. If the sediment surface is flat and unobstructed, it could be possible to lower the magnetic sensor and decrease the measurement spacing to allow objects 1-2 m apart to be separately resolved.

Triaxial vector magnetic measurements have greatly aided the search for magnetic materials from boreholes (Silva and Hohmann 1981). These same procedures could be applied to estimating the depth of iron in the sediment and, therefore, could suggest its age.

Handheld metal detectors have been applied to search for artifacts at shipwrecks (Colani 1966), but other instruments could be more suitable for large area investigation of insulators and conductors. Electrical resistivity measurements can be made on the sea floor by dragging an electrical cable with several connection points exposed to the seawater (Orellana 1982, p. 386; Terekhin 1962). Magnetotelluric surveys typically measure to a great depth (Moose 1981, Gregori and Lanzerotti 1979), but might be suitable for this survey. Other techniques for measuring sea floor conductivity are also possible (Bannister 1968, Coggon and Morrison 1970).

Old iron could be significantly different from modern iron in its magnetic properties. An electromagnetic induction system which measures the electrical conductivity of the sea floor could also determine its AC magnetic susceptibility. Measurements at one or more frequencies might allow different ferrous materials to be distinguished. With the vector magnetometer mentioned above, it could be possible to separate the remnant and induced magnetization of iron objects by determining the net direction of polarization. The ratio of remnant to induced magnetization, the Koenigsberger ratio (Parasnis 1979, p. 13), might distinguish old iron from modern steel.

While all of the ideas mentioned here have been applied in geophysics, further investigation will be needed to see if any of them could really aid the geophysical search for historic shipwrecks.

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Table 10.1

Line #1 - Run Directly Over Wreck of Will O' Wisp*

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	0	0
2	0	10	0
3	0	20	0
4	0	30	0
5	0	40	0
6	+6	50	10
7	+7	60	10
8	+7	70	20
9	+18	80	30
10	+56	90	40
11	+216	100	50
12	+2659	110	60
13	-311	120	70
14	-122	130	80
15	-33	140	90
16	-14	150	100
17	-6	160	110
18	-3	170	120
19	-4	180	130
20	0	190	0
21	0	200	0

*Tow depth: surface
Target depth: 3 meters
Tow speed: 3.5 knots
Sensitivity: $\pm$ 1 nt

Table 10.2

Line #2 - 50 Meters South of Will O' Wisp

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	0	0
2	0	10	0
3	0	20	0
4	-1	30	0
5	-4	40	10
6	-9	50	20
7	-9	60	30
8	-3	70	40
9	+18	80	50
10	+48	90	60
11	+46	100	70
12	+25	110	80
13	+18	120	90
14	+11	130	100
15	-4	140	110
16	-3	150	120
17	-4	160	130
18	-5	170	140
19	0	180	0
20	0	190	0
21	0	200	0

Table 10.3

Line #3 - 75 Meters South of Will O' Wisp

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	10	0
2	0	20	0
3	0	30	0
4	0	40	0
5	-2	50	0
6	0	60	10
7	0	70	20
8	-3	80	30
9	-5	90	40
10	+3	100	50
11	+2	110	60
12	+9	120	70
13	+11	130	80
14	+8	140	90
15	+8	150	100
16	+6	160	110
17	+4	170	120
18	+7	180	130
19	+5	190	140
20	+3	200	150
21	0	210	0

Table 10.4

Line #4 - 100 Meters South of Will O' Wisp

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	10	0
2	0	20	0
3	0	30	0
4	0	40	0
5	0	50	0
6	-2	60	0
7	-5	70	10
8	-9	80	20
9	-4	90	30
10	-2	100	40
11	-1	110	50
12	0	120	60
13	-3	130	70
14	0	140	80
15	-1	150	90
16	0	160	100
17	+1	170	110
18	+1	180	120
19	+1	190	130
20	+2	200	140
21	+1	210	150
22	+1	220	160
23	0	230	0

Table 10.5

Line #5 - 125 Meters South of Will O' Wisp

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	0	0
2	0	10	0
3	0	20	0
4	0	30	0
5	0	40	0
6	+6	50	10
7	+7	60	10
8	+7	70	20
9	+18	80	30
10	+56	90	40
11	+216	100	50
12	+2659	110	60

Table 10.6

Line #6 - 150 Meters South of Will O' Wisp

#	Amplitude (nanoteslas,nt)	Time (sec)	Duration (sec)
1	0	10	0
2	0	20	0
3	0	30	0
4	0	40	0
5	0	50	0
6	+1	60	10
7	+2	70	20
8	0	80	30
9	+2	90	40
10	-1	100	0
11	0	110	0
12	0	120	0
13	0	130	0
14	0	140	0
15	0	150	0

Table 10.7

Amplitude Values

Line #	Amplitude (nanoteslas)	Distance (meters)
1	2659	0
2	46	50
3	11	75
4	9	100
5	4	125
6	2	150

Table 10.8

Signature Values

Line #	Signature	Distance (meters)
1	dipolar	0
2	dipolar	50
3	monopolar	75
4	dipolar(?)	100
5	monopolar	125
6	monopolar	150

Table 10.9

Duration Values

Line #	Time (sec)	Distance (meters)
1	2659	0
2	130	50
3	140	75
4	150	100
5	70	125
6	40	150

Table 10.10

Selected Magnetic Anomalies

SINGLE OBJECTS

Sensor Height in feet	Object	Size of Object in feet	Magnetic Area in feet	Inflection in Gammas
3	cable	70 x 1 in.	173 x 89	380
15	camshaft	20 x 2 in.	50 x 45	45
4	cast iron soil pipe	10; 100 lbs.	65 x 45	1407
4	anvil	150 lbs.	26 x 26	598
4	kettle	22 in. dia.	26 x 26	59
16	anchor	6 foot shank	270 x 80	30
3	pipe	3 in. dia.	45 radius	550*
8	pipe	20 x 10 in. dia. 10 in. dia.	160 x 90	180

MULTIPLE OBJECTS

Sensor Height in feet	Object	Size of Object in feet	Magnetic Area in feet	Inflection in Gammas
5	pipe & bucket	8 x 1 in. dia.	60 x 50	250
15	cable & chain	60 in. @	50 x 40	30
5	burn pile charcoal	8 dia. x 3 in.	40 x 30	20
6	burn area charcoal	30 x 20 x 1	120 x 70	15
10	pyrite	noduals	350 x 150	310
10	metal stairs & "I" beam	14 x 3 x .8 10 x 1	150 x 140	100
15	scattered ferrous metal	90 lbs.	110 x 90	100
20	WW II naval refuse (paint buckets, 55 gal drums, mop pails, cable, etc.)	mixed	550 x 450	361

Table 10.10 (cont'd)

Selected Magnetic Anomalies

WRECKAGE

Sensor Height in feet	Object	Size of Object in feet	Magnetic Area in feet	Inflection in Gammas
4	Star of the West ocean going side-wheel steamer	228 x 32	350 x 350	7650
16	Wando River wreck coastal trader	90 x 20	250 x 150	35
8	gas sternwheel boat	50 x 10	200 x 140	450
12	Lotawana river steamboat	180 x 47	350 x 300	310
20	Constante merchant sail	128 x 26	250 x 150	60
10	Steamer Spray	140 x 19	180 x 160	520
8	James Stockton schooner	55 x 19	130 x 90	80
20	CSS Tuscaloosa ironclad	150 x 40	300 x 200	4000
3	segment of a shrimp boat	27 x 5	90 x 50	350
12	keeled barge	92 x 22	250 x 250	180
8	river trader sail	44 x 13	120 x 100	100
12	1840's tow boat	65 x 13	110 x 60	110

All values in feet unless otherwise noted. * Denotes monopole; all other anomalies are dipolar (A.R. Saltus 1986).